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Original Communication

Sexing of human hip bones of Indian origin by discriminant function analysis

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Abstract

The present study was carried out in terms of discriminant analysis and was conducted on 100 human hip bones (of unknown sex) of Indian origin. Based on morphological features, each of the hip bone was rated on a scale of 1–3 for sexing. Twelve measurements and five indices were recorded. The results of discriminant function analysis showed that the acetabular height (vertical diameter) and indices 1 (total pelvic height/acetabular height), 2 (midpubic width/acetabular height) and 3 (pubic length/acetabular height) were very good measures for discriminating sexes. Pelvic brim depth, minimum width of ischiopubic ramus and indices 4 (pelvic brim chord × pelvic brim depth) and 5 (pubic length × 100/ischial length) were also good discriminators of sex. The remaining parameters were not significant as they showed a lot of overlap between male and female categories. The results indicated that one exclusive criterion for sexing was index 3 (pubic length/acetabular height). In comparison with the morphological criteria, the abovementioned index caused 25% and 10.25% increase in the hip bones of female and male category, respectively.

Keywords: Hip bone; Sex estimation; Discriminant function analysis; Physical anthropology

1. Introduction

The four main features of biological identity are sex, age, stature and ethnic background. A reliable estimation of sex from the skeleton by using various criteria is important while dealing with undocumented skeletal material, whether it is in the field of medicine or work with prehistoric osteological collections. It is well known that skeletal characteristics vary among populations, therefore each population should have specific standards to optimize the accuracy of identification. Although many bones of the skeleton present size related sexual differences, those of the pelvis usually display marked sex differences in morphology independent of size due to different reproductive functions mainly influenced by sex hormones.[1] The distinctive morphology of the human hip bone and its clear sexual dimorphism makes it of interest from anatomical, anthropological and forensic points of view. It can therefore be a reliable criterion for estimation of sex of skeletal remains under study.

Methods of determining the sex of an individual based upon skeletal remains can be divided into three broad categories.

The first category is of visual criteria, based on morphological or subjective observations like subpubic angle, sciatic notch, preauricular sulcus, auricular area etc. As a general rule, male bones are larger and heavier than female ones,[2] but there may be an overlap of ranges of variation of male and female bones based on these features, therefore their accuracy depends upon the experience of researchers.[1]

The second category for sexing of the hip bones is based on the measurements or metric techniques e.g. ischiopubic index, pubic angle, pubic length etc.[3–6] The major problem however is that this method requires most of the bone to be intact and the measurements and indices thus calculated have to be compared with a chart of male and female

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values which is very time consuming, especially when a whole series of skeletons are under study.

The third category of methods utilized for sex determination of skeletal remains is discriminant function analysis, a concept first introduced by Fisher in anthropology.[7–9] This method has the practical advantage of permitting sexual assessment of poorly preserved remains. However little work has been undertaken using this method in Indian population. To compensate for this paucity of information, sexing of hip bones by discriminant function analysis was undertaken in the present study.

2. Materials and methods

The study was conducted in the Department of Anatomy, Lady Hardinge Medical College, New Delhi on 100 dry adult human hip bones of unknown sex without any congenital or iatrogenic deformity. The hip bones obtained were a part of osteological collection of the medical colleges of Delhi. Measurements were taken with the help of Vernier calipers, metallic scale and goniometer.

The procedure for determination of sex was carried out as follows:

2.1. Morphological sexing

This was based on observations of experienced anatomists of our department. The following nine morphological features were used for sex determination:

- Preauricular sulcus.[10]
- Greater sciatic notch.[10]
- Obturator foramen.[10]
- Iliac fossa.[10]
- Comparison between diameter of acetabulum and the distance of its anterior rim from pubic symphysis.[10]
- Ischiopubic ramus eversion.[10]
- Ventral arc.[11]
- Subpubic concavity.[11]
- Ridge on medial aspect of ischiopubic ramus.[11]

Based on the above morphological features (Table 1), each hip bone was classified in three categories for sexing namely male, female and indeterminate.

Table 1
Differences in morphological traits in male and female hip bones

Trait	Male expression (−)	Female expression (+)
Preauricular sulcus	Absent	Present
Greater sciatic notch		
(a) Posterior angle	Narrow	Wide
(b) Width	Narrow	Broad
Obturator foramen's shape	Oval	Triangular
Iliac fossa	Shallow	Deep
Acetabulum		
(a) Diameter	Wide	Narrow
(b) Distance of the anterior rim of acetabulum from pubic symphysis vis-à-vis diameter	Less	More
Ischiopubic ramus eversion	Present	Absent
Ventral arc on body of pubis	Absent	Present
Subpubic concavity	Absent	Present
Ridge on the medial aspect of ischial tuberosity extending to ischiopubic ramus	Absent	Present

2.2. Metric sexing

This was done by measuring the following 12 parameters of the hip bone. The measurements were done to the nearest tenth of a millimeter using vernier calipers and a metallic scale and the pubic angle was measured by using a goniometer (Figs. 1–4).

- *Total pelvic height*. The longest hip bone dimension, measured from the highest point on the iliac crest to the deepest point of ischial tuberosity (inferior most point on iliac tuberosity).[12]
- *Pelvic (iliac) width*. It was measured as straight distance from anterior superior iliac spine to posterior superior iliac spine.[13]
- *Acetabular height (diameter)*. It was taken as the diameter of acetabulum measured along the axis of the body of ischium.[13]
- *Midpubic width*. It was measured as the shortest distance from the midpoint of pubic symphysis to the nearest obturator foramen margin.[13]
- *Pubic length*. It was taken as straight distance from the mid point of acetabulum (from dorsal aspect, the point where the three elements forming the hip bone meet) to the uppermost margin of pubic symphyseal surface.[14]
- *Pelvic brim chord*. It was measured as the straight distance from the auricular point (defined as intersection of arcuate line with anterior edge of auricular surface) to the uppermost edge of pubic symphyseal surface.[13]
- *Pelvic brim depth*. It was taken as the perpendicular distance from the midpoint of pelvic brim chord to the pelvic brim.[13]
- *Minimum pubic width*. It was defined as the least straight distance from pubic symphyseal surface to the nearest obturator foramen margin.[15]
- *Pubic angle (inter-rami angle)*. It was measured as the angle formed between the long axis of superior and inferior ramus of pubis.[15]
- *Minimum width of ischiopubic ramus*. It was measured as the least straight distance between the ischiopubic ramus and nearest obturator foramen margin.[15]
- *Acetabular symphyseal breadth*. It was measured as the straight distance between the outermost point of the posterior margin of acetabulum and the midpoint of pubic symphyseal surface.[16]
- *Ischial length*. It was measured as the distance from the anterior most edge of the body of ischium to the midpoint of acetabulum (from dorsal aspect, point in the acetabulum where the three elements forming the hip bone meet).[14]

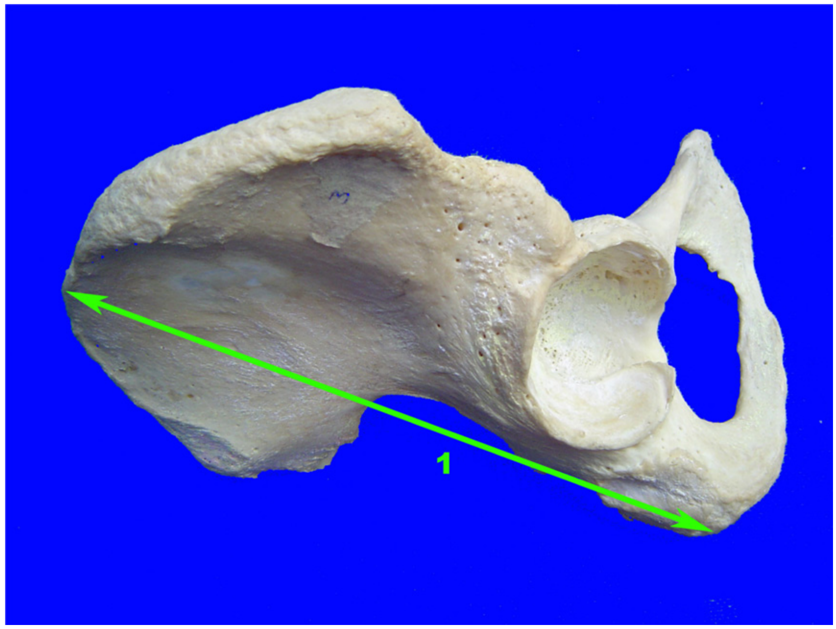

Fig. 1. Measurement of total pelvic height (1).

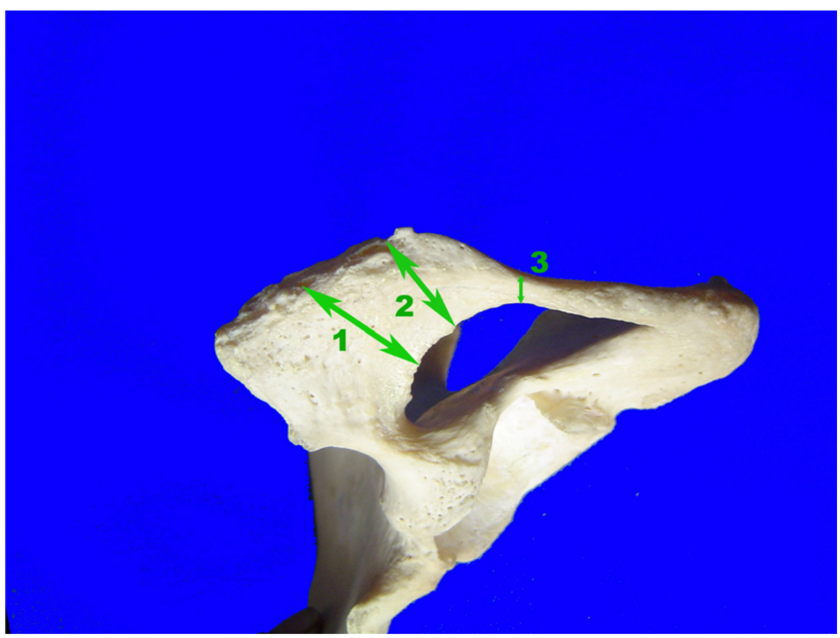

Fig. 2. Measurements of midpubic width (1), minimum pubic width (2) and minimum width of ischiopubic ramus (3).

2.3. Indices

Pelvic measures were combined into the following indices:

- Total pelvic height/acetabular height (diameter).
- Midpubic width/acetabular height (diameter).
- Pubic length/acetabular height (diameter).
- Pelvic brim chord × pelvic brim depth.
- Ischiopubic index = pubic length × 100/ischial length.[14]

2.3.1. Sexing analysis

The measurements and indices were analyzed according to the principles of the multivariate discriminant function technique. In our study, the hip bones were classified into three categories using morphological criteria. The variables (12 measurements and five indices calculated on each hip bone) were entered in a stepwise discriminant function procedure to determine the single most important variable between the sexes. This procedure used Wilk's lambda, which calculates the usefulness of a given variable and

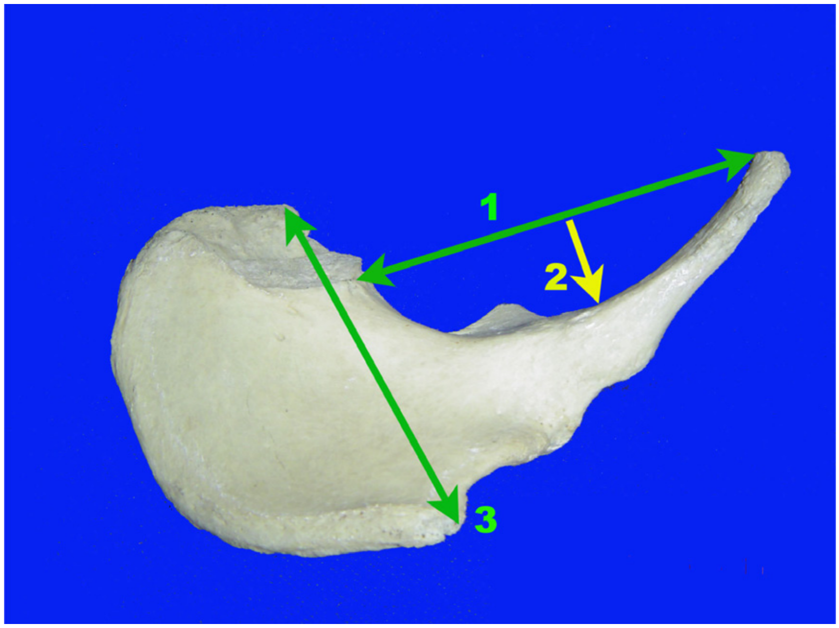

Fig. 3. Measurements of pelvic brim chord (1), pelvic brim depth (2) and pelvic (iliac) width (3).

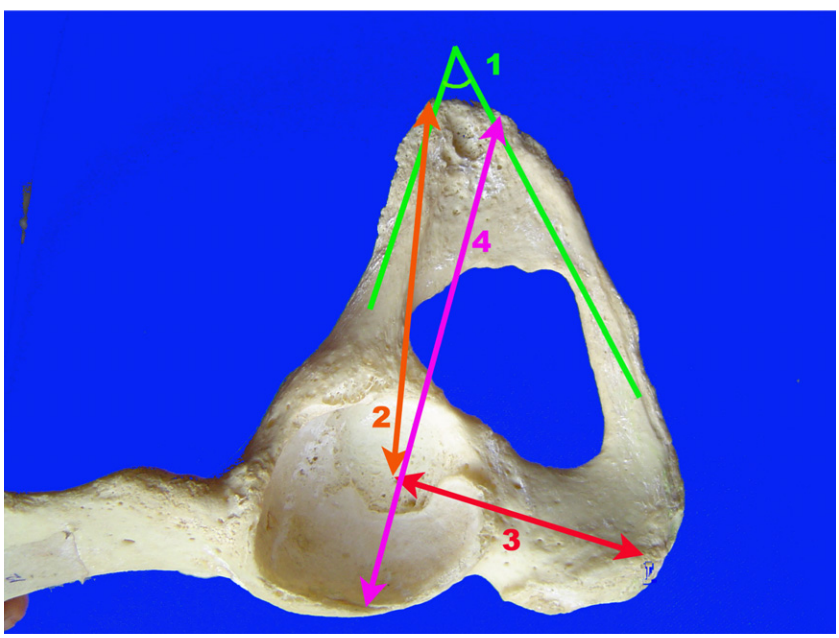

Fig. 4. Measurements of pubic (inter-rami) angle (1), pubic length (2), ischial length (3) and acetabular symphyseal breadth (4).

F-ratio which defines quantum of variation that exists within and between the sexes and the significance level of the variance (with $F = 3.84$ to enter and $F = 2.71$ to remove). In stepwise analysis, all pelvic variables were systematically added and removed from the list. Once the best variable was selected, it was removed from the analysis and the remaining variables reassessed and selected.

Further, coefficients which form the discriminant function were obtained for each measurement and these helped in replacing several measurements by a single value called the discriminant function score.

Predicted groups of all the observations were calculated by giving equal weightage to all the variables and also by using the most discriminant criterion and then compared with the observed groups.

3. Results

The study included 100 intact human hip bones. Side determination of each of them was done and these were then classified into three categories according to nine mor-

phological features. The number of bones in each category are shown in Table 2.

The results of the discriminant function analysis with respect to Wilk's lambda and F ratio are shown in Table 3.

Acetabular height and indices 1, 2 and 3 were found to be very highly significant for sexing ($P = 0.000$). Pelvic brim chord, pelvic brim depth, minimum width of ischio-pubic ramus and indices 4 and 5 also showed high significance. The function coefficients obtained for all the parameters are shown in Table 4.

Among all the parameters and indices, index 3 (pubic length/acetabular height) was found to be the most discriminant criterion for sexing. The functional coefficients obtained by index 3 are shown in Table 5.

The coefficients can be placed in the form of an equation and applied to another sample of unknown sex. For example, if the value of index 3 for a hip bone of unknown sex is "A", then

For "Female", function score is $= -140.767 + (171.403 \times A)$.
For "Indeterminate", function score is $= -114.892 + (154.648 \times A)$.
For "Male", function score is $= -101.324 + (145.092 \times A)$.

Table 2
Distribution of bones according to morphological criteria

Category	Number of bones
Female	28
Indeterminate	33
Male	39
Total	100

Table 3
Test of equality of group means

	Wilks' Lambda	F	P value
Total pelvic height	0.953	1.179	0.325
Pelvic width	0.967	0.808	0.523
Acetabular height	0.786	6.464	0.000***
Midpubic width	0.947	1.341	0.260
Pubic length	0.910	2.358	0.059
Pelvic brim chord	0.876	3.360	0.013*
Pelvic brim depth	0.834	4.735	0.002**
Minimum pubic width	0.978	0.546	0.702
Pubic angle	0.920	2.074	0.090
Minimum width of IP ramus	0.836	4.664	0.002**
Acetabular symphyseal breadth	0.991	0.224	0.925
Ischial length	0.966	0.835	0.506
Index 1	0.810	5.555	0.000***
Index 2	0.805	5.762	0.000***
Index 3	0.641	13.274	0.000***
Index 4	0.817	5.331	0.001**
Index 5	0.813	5.470	0.001**

* Significant (P value < 0.05).
** Highly significant (P value < 0.01).
*** Very highly significant (P value < 0.001).

Table 4
Function coefficients of all variables

Measurement	Category		
	Female	Indeterminate	Male
Total pelvic height	−549.472	−549.074	−549.721
Pelvic width	1.066	1.033	1.05
Acetabular height	1911.655	1912.592	1915.505
Midpubic width	555.723	554.95	555.774
Pubic length	−388.252	−388.831	−390.218
Pelvic brim chord	33.176	32.893	32.667
Pelvic brim depth	191.549	191.771	191.691
Minimum pubic width	−19.769	−19.841	−19.651
Pubic angle	17.488	17.49	17.655
Minimum width of IP ramus	−3.329	−3.223	−3.368
Acetabular breadth	−20.049	−20.273	−20.242
Ischial length	234.32	234.482	235.29
Index 1	−28323.51	−28274.52	−28318.383
Index 2	28162.119	28154.326	28185.769
Index 3	9121.978	9134.291	9156.996
Index 4	−1.771	−1.774	−1.773
Index 5	143.999	144.114	144.591
Constant	−58010.848	−58039.26	−58210.959

Table 5
Function coefficients of index 3

	Category		
	Female	Indeterminate	Male
Index 3	171.403	154.648	145.092
Constant	−140.767	−114.892	−101.324

Table 6
Comparison between number of hip bones in each category using morphological criteria and index 3

Category	Using morphological criteria	Using index 3
Female	28	35
Indeterminate	33	21
Male	39	43

The values of the function scores are compared for all the categories. The hip bone of unknown sex belongs to the category for which the value is highest.

The categorization of hip bones was done by using morphological criteria and index 3. The number of bones in each category is shown in Table 6.

4. Discussion

The results showed that acetabular height (vertical diameter) and indices 1, 2 and 3 were best measures for discriminating sexes. Pelvic brim depth, minimum width of ischiopubic ramus and indices 4 and 5 were also good discriminators of sex. The remaining parameters can be ignored, as they show overlap between male and female categories.

The single best variable found by discriminant function analysis in our study was index 3 (pubic length/acetabular

height) which can be used as one exclusive criterion for sexing. Index 3 was a better criterion for sexing of hip bones than the morphological criteria as evident from Table 6.

The percentage increase in the bones obtained by using index 3 in female and male category was 25% and 10.25%, respectively. The percentage decrease obtained for indeterminate category was 36.36%.

Schulter–Ellis et al. calculated acetabulum/pubis ratio in North American Eskimo and Indian innominate bones and indicated it to be the single best discriminating ratio which when used alone classified 95% of the specimens of their study.[17]

The pubic bone was found to be longer in females than males, but the differences were believed to appear after puberty. In the fetus[18] and during first year of life,[19] there were no sex differences in the length of pubic bone. In males, the pubis grew at the same rate as ischium, while in females of 3–7 years of age, the length of pubic bone started increasing in comparison.[3] Greulich and Thomas had shown that the pelvic inlet of females grew extremely rapidly for approximately 18 months at puberty reaching typical female size and form. The change in shape of pelvic inlet was mainly due to growth of pubic bone. This excess growth in various parts of pelvis at puberty had hormonal basis. It was seen that length of pubic bone was the best indicator of the sex of the skeleton because it was most responsive to the action of female hormones.[20]

The traditionally used criteria for sex differentiation like subpubic angle, height of the pubic symphysis and shape of obturator foramen were all secondary to the elongation of the pubic bone. Therefore measuring the length of pubis directly was advantageous as it gave the estimate of primary variable and the researchers did not run the risk of counting the same difference over and over again. The pubic length is also included in both the saggital and transverse diameters of the pelvic inlet and hence it is a dimension of the pelvis which shows extreme sexual differentiation and which has a low variability compared to diameters. Arsuga et al. included pubic length as one of the parameters of pelvic inlet which was adapted in female bones for reproduction.[21] Patriquin et al., in their work on South African black and white pelves, found that at 88% of average accuracy, the most discriminating traits were pubic bone shape and subpubic concavity form.[22]

The other parameter used in derivation of index 3 is acetabular height which sharpens the contrast between the sexes by emphasizing the smaller acetabular size in females in conjunction with their greater pubic length. Use of this measurement for the discriminant function in the present study has a practical advantage of permitting sexual assessment of poorly preserved remains seen commonly in archeological excavations and forensic investigations. Acetabulum is commonly preserved in the fragmentary remains of the hip bones. Coleman stated that if a researcher chooses to include acetabular size in an analysis, it should be evaluated metrically.[23] The time saved through morphological assessment of this feature cannot compensate for the resulting low precision in sexing.

Our findings of acetabular height analysis corresponded with the findings of Milne,[13] who also worked on bones of unknown sex. Scott, Baker and Murphy, who worked on New Zealand Polynesian skeleton, had similar findings.[24–26] Genovese proposed that this was one of the best dimensions for sexing and found it to be greater in males,[27] a finding supported by Rajangam et al. who worked on bones of Karnataka origin and Patriquin et al.[12,28]

We found index 1 (total pelvic height/acetabular height) to be significant for sexing, in contrast to the findings of Milne.[13] Our result for index 2 (midpubic width/acetabular height) as a good discriminator of sex was in corroboration with his study.[13] Index 1 is a good measure of sexing because it includes acetabular height, a parameter which showed reliable discriminating power independently.

Pelvic brim depth was an efficient discriminator of sex while pelvic brim chord was not, a finding also observed by Milne.[13] Segebarth-Orban also demonstrated in Belgium and French population that females had significantly greater pelvic brim depth which they interpreted as being due to greater curvature of the arcuate line resulting in a wider pelvic inlet.[29] Our findings of significance of minimum width of ischiopubic ramus for sexing can be explained by the relation between the ischiopubic ramus and the shape of pelvic outlet which is adapted to the process of reproduction.

Index 4 (pelvic brim chord/pelvic brim depth) was found to be a good sexing parameter similar to the results of Milne and Arsuga et al.[13,21] The findings of Holland et al.[30] were in contrast to ours, as these indicated that the female hip bones were different from males in those traits which were associated with a relatively larger pelvic inlet (a greater degree of curvature of the iliopectineal line and more posterior position of the auricular surface).

The results of our study indicated that index 5 (ischiopubic index) was noted to be a good indicator of sex, corroborating with the findings of Milne.[13] Seidler showed similar results with only 4.71% of bones left unclassified by using the discriminant function of this index alone.[31] The sexual differences of ischiopubic proportions reflected the adaptation of the female pelvis to parturition and the result of remodeling of the female bony pelvis during puberty.

Among other parameters, total pelvic height was postulated to be a good indicator of sex by, Milne, Rajangam et al. and Segebarth-Orban which was in contrast to our study.[13,28,29] We interpreted that this parameter was a size related measure and did not show sex related variation.

Ischial length was found to be a significantly useful measure by Patriquin et al. and Segebarth-Orban,[12,29] which did not match with the findings of our study.

Meindl et al. considered that the female skeleton was seldom incorrectly diagnosed. He suggested it to be due to less variability in female pelvic size, since they were under strong selective pressures related to adaptations in locomotion as well as reproduction.[32] Phenice also reported his

procedure to be slightly more accurate for females than males.[11] Our study also showed that percentage increase in bones of female category was more than that of male category after using discriminant functions of index 3. It may be due to limited variability in female pelvis due to the combined functional requirements of childbirth and locomotion.

It was concluded that when discriminant function analysis was applied for sexing, it showed an increase in the percentage of bones in male and female category with reduction in the number of bones in the indeterminate category. It can further be concluded that discriminant function analysis scored over the morphological criteria by reducing the observer subjectivity in sexing of hip bones. Finally it can be summarized that the present study provided function coefficients of hip bones of Indian population for sexing which gave group specific standards valuable in forensic and archeological analyses. However, a limitation of our study was that the bones used were disarticulated and no previous information about their sex was available.

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